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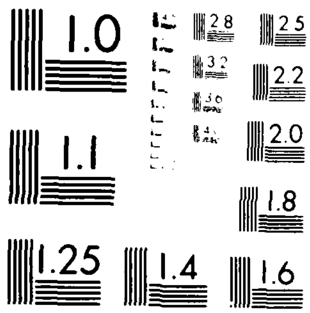

MICROCOPY RESOLUTION TEST CHART

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AD-A134 425

DOT/FAA/CT-83/40

Survey of Characteristics of Near Mid-Air Collisions Involving Helicopters

Barry R. Billmann

May 1983

Final Report

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16. Abstract

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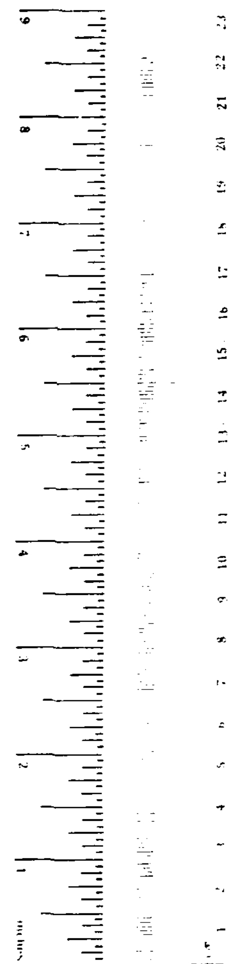
METRIC CONVERSION FACTORS

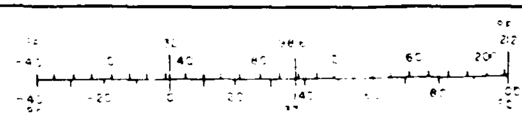
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECTUTIVE SUMMARY

The Minimum Traffic Alert and Collision Avoidance System (TCAS) II is nearing the limited deployment phase in its development cycle. The system has been developed primarily for installation on air carrier aircraft. The development of the system has focused on the operating characteristics of transport aircraft. Rotorcraft operating characteristics may require a collision advoidance system with substantially different functional performance than exists in the Minimum TCAS II System. This paper has been prepared to provide analysis of environmental conditions and operational characteristics of near mid-air collision situations involving rotorcraft. The analysis is intended to provide data in establishing preliminary human factors and procedural design requirements for a rotor collision avoidance system.

The significant conclusions that resulted from the analysis include:

1. The distribution of locations of near mid-air collisions involving rotorcraft and the rotorcraft density distribution do not coincide.

2. The near mid-air encounters involved two helicopters less than 5 percent of the time.

3. A disproportionally large percentage of the near mid-air collisions involved helicopters performing utility missions and/or military aircraft flying high-airspeed, low-altitude training routes. The ability of TCAS II logic to adequately resolve encounters during accelerating flight is limited. As a result, a nonnegligible percentage of encounters involving helicopters may not be resolved with TCAS resolution logic.

4. In a majority of the near mid-air encounters, both aircraft probably would have been Mode C encoder equipped.

5. A significant proportion of the encounters involved an intruder approaching the helicopter from the rear quadrant (5, 6, 7, o'clock).

6. The helicopter was less then 500 feet above ground level in one-third of the encounters. Only 25 percent of the near mid-air collisions involved helicopters more than 1,500 feet above ground level. Radio-frequency (RF) characteristics in this environment, such as multipath, must be investigated.

7. In 12 percent (23 cases) of the incidents, visibility was reported as 3 miles or less even though the reporting party also stated he was operating visual flight rules in 94 percent of the encounters.

8. In more than one-half of the incidents, at least one aircraft was being provided some form of air traffic control services. In 20 percent of the incidents, at least one aircraft was given traffic advisory information prior to closest point of approach.

INTRODUCTION

PURPOSE.

Rotorcraft operating characteristics may require a collision avoidance system to perform a substantially different service than is provided to conventional fixed wing aircraft by Traffic Alert and Collision Avoidance System (TCAS) I or the Minimum TCAS II. The information required by helicopter pilots to avoid near mid-air encounters may be different than information needed by airplane pilots. This paper has been prepared to provide analysis of environmental conditions and operational characteristics of new mid-air collision situations involving rotorcraft. The analysis is intended to provide data in establishing preliminary human factors and procedural design requirements for a rotorcraft collision avoidance system. The information should be used to establish TCAS Rotorcraft Program experimental requirements.

SCOPE.

The near mid-air incidents and mid-air collisions which were analyzed all involved at least one helicopter. The near mid-air incident data were obtained from the Aviation Safety Reporting System sponsored by National Aeronautics and Space Administration (NASA). This data base consisted of 187 incident reports which occurred between March 1978 and December 1982. Additional data on mid-air collisions were obtained from the United States Army Safety Center at Fort Rucker, Alabama, and included information on six mid-air collisions involving at least one military helicopter. The period covered was from April 1972 to December 1981. The data bases used had been specifically developed for aviation safety and accident prevention purposes. Data used from these sources have not been checked for authenticity.

METHODOLOGY.

Each incident report and narrative summary was reviewed. Specific data were collected from the computer listings of the parameters describing the incidents. The narrative descriptions ranged from a very brief form of a couple sentences to a very detailed form of several pages. The narrative descriptions provided information which was used to further quantify the characteristics of the encounters.

CHARACTERISTICS OF THE INCIDENTS

GEOGRAPHIC LOCATION.

The location of each incident which occurred in the Continental United States was plotted and is shown in figure 1. There were 13 incidents which did not occur within the Continental United States. Of these 13 incidents, 3 occurred in the Panama Canal Zone, 2 occurred in Hawaii, 2 occurred in Okinawa, and 1 occurred in Alaska. There were 5 occurrences over oceanic areas.

FIGURE 1. LOCATION OF NEAR MID-AIR INCIDENTS IN THE CONTINENTAL UNITED STATES

A large portion of the incidents occurred in California. Most of these were concentrated in the Los Angeles Basin area. It is interesting to note the geographic distribution of incidents differ considerably from the density distribution of helicopter home bases (reference 1). Significantly, there was an extremely low number of incidents (4) in the extremely high helicopter density along the Texas and Louisiana gulf coasts. This fact may result from the high degree of standardized operating procedures which have been developed in this area. This area is also identified as an Alert Area (A-381) with high concentration of helicopter operations below 2,000 feet mean sea level. Helicopter density in itself does not appear to be a problem. Only 3 of the 187 near mid-air collision reports involved two helicopters.

Review of the narratives uncovered another interesting geographical fact. Fifteen incidents involved helicopters which were departing from, en route to, or arriving at, mining sites located in the Appalachian mountains. All the incidents reported in Tennessee, Kentucky, West Virginia, and Ohio were of this type. Additionally, two out of four occurrences in Pennsylvania, and one out of eight occurrences in Virginia were of this type. All 15 incidents involved only one helicopter.

The high number of incidents which occurred in southeastern Alabama and the Florida panhandle reflects the high concentration of military student rotary wing instrument flight training being conducted in visual flight rules (VFR) conditions in this area. The Army's Aviation Training Center is located at Ft. Rucker, Alabama, and the Navy conducts its training at Pensicola, Florida. Several of the incidents occurred in the Military Operations Area (MOA) near Milton, Florida. However, only one incident involved two military aircraft.

Several common factors were identified from the narratives for the occurrences in southern California. The common factors include:

1. Reported reduction in visibility was due to smog, smoke, or sun position.

2. The aircraft reporting the incident was in contact with an air traffic control (ATC) facility (reported in 55 out of 70 incidents).

3. Aircraft were operating under VFR in Visual Meteorological Conditions (VMC), although weather conditions were cited as a contributing factor by the reporting party in 15 percent of the incidents.

REPORTING PARTY.

The near mid-air collision reports contained information identifying the function (pilot, copilot, passenger, etc.) of the party making the report. In only four cases was the party not identified. In 64 percent of the cases (124) the report was prepared by the pilot, crew member, or passenger of the rotorcraft. In 43 cases (22 percent) the incidents were reported by the pilot or copilot of the fixed wing aircraft involved. In these cases the helicopter was considered as the intruder. Nine percent were reported by ATC or Flight Service Station (FSS) personnel. There were multiple reports on four separate incidents. Two of the four incidents were reported by both pilots. The other two incidents were reported by three separate parties -- both pilots and an air traffic controller.

Recall that in only three incidents both aircraft involved were helicopters. The statistics gathered on the reporting party indicate more than twice as many reports were initiated by the helicopter crews than by the fixed wing crews. Two unsubstantiated conclusions can be made:

1. The generally greater cockpit visibility afforded by helicopters permitted easier intruder detection. Similar incidents were undetected by the fixed wing crews.

2. Helicopter personnel may have sensed higher levels of urgency than were sensed by the fixed wing personnel. Since almost all rotorcraft operations are classed as commercial operations, this may be due to a higher level of training and safety awareness of the helicopter pilot when compared to the average general aviation pilot.

TYPE OF OPERATION.

Each report was reviewed in order to identify the type of operation associated with the aircraft involved in the incident. The operation type was classified as reported in the near mid-air collision and accident report summaries.

The recap of type of operation is presented in figure 2. Figure identifies the type of operation for both aircraft involved in the incident.

Although the type of operation was not reported in almost one- of the incidents, a couple of points should be mentioned. Rotorcraft traini operations were involved in 19 percent of the incidents. This probably reflects the active participation of the military services in NASA's Aviation Safety Reporting System. Utility operations such as logging, pipeline patrol, forest fire work, etc., accounted for the second highest proportion of helicopter operations. These operations generally involve frequent changes in the heading, airspeed, and/or altitude of the helicopter. These types of maneuvers reduce the ability to accurately provide predictive information about the future relative position of the aircraft during a near mid-air encounter. During these types of operation the only viable collision avoidance information may be simply the current position of the intruder. The classification of utility operations did not include some other forms of operations which involve frequent maneuvering. One such type was agricultural application. This type of operation was grouped in the other catagory.

In only 38 percent of the incidents was the type of operation of the other aircraft identified. The two most predominant types of operation were training and low-level, high-speed military training. Each type of operation occurred 23 times. The altitudes above ground level (AGL) at which helicopters operate make high-speed, low-level military training a significant hazard to the helicopter when not operating in controlled airspace. Several of the incidents included recommendations to chart the width of the military training route (MTR) to scale on VFR sectional navigation charts. Also, remarks included the request by the Federal Aviation Administration (FAA)/Department of Defense (DOD) to provide more current information on the activity status of the routes.

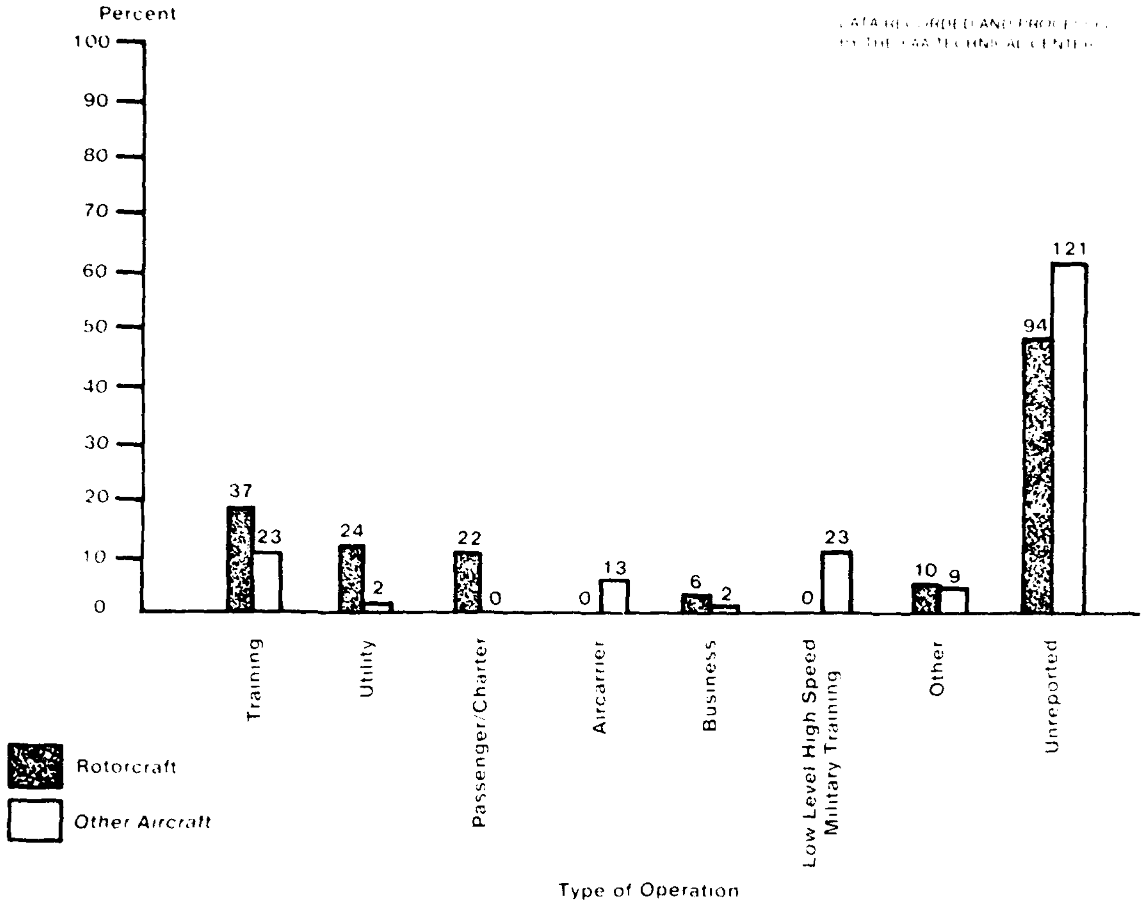

FIGURE 2. DISTRIBUTION OF OPERATION TYPE

SIZE OF AIRCRAFT. One important consideration in reviewing the incidents is determining if the aircraft involved were equipped with Mode C transponders. The information was not available in the reports. However, the aircraft were classified according to gross weight. This information can be used as an indicator of possible Mode C transponder equipment status. Figures 3 and 4 identify the aircraft gross weights for the aircraft involved in the incidents. Figure 3 presents the data for cases which were reported by helicopter crews. Figure 4 presents the data in cases where the reporting party was not on board the helicopter. Since virtually all military aircraft have Mode C transponders, all military aircraft were grouped together regardless of gross weight.

In at least one-half the cases reported by helicopter pilots, the intruding aircraft probably was equipped with a Mode C transponder, since most airplanes over 5,000 pounds gross weight are equipped with Mode C transponders. About one-quarter of the helicopters were classed as small (less than 5,000 pounds gross weight). The percentage of these which would be Mode C equipped is unknown. However, at least 75 percent of the helicopters probably were Mode C equipped in cases reported by the helicopter crews.

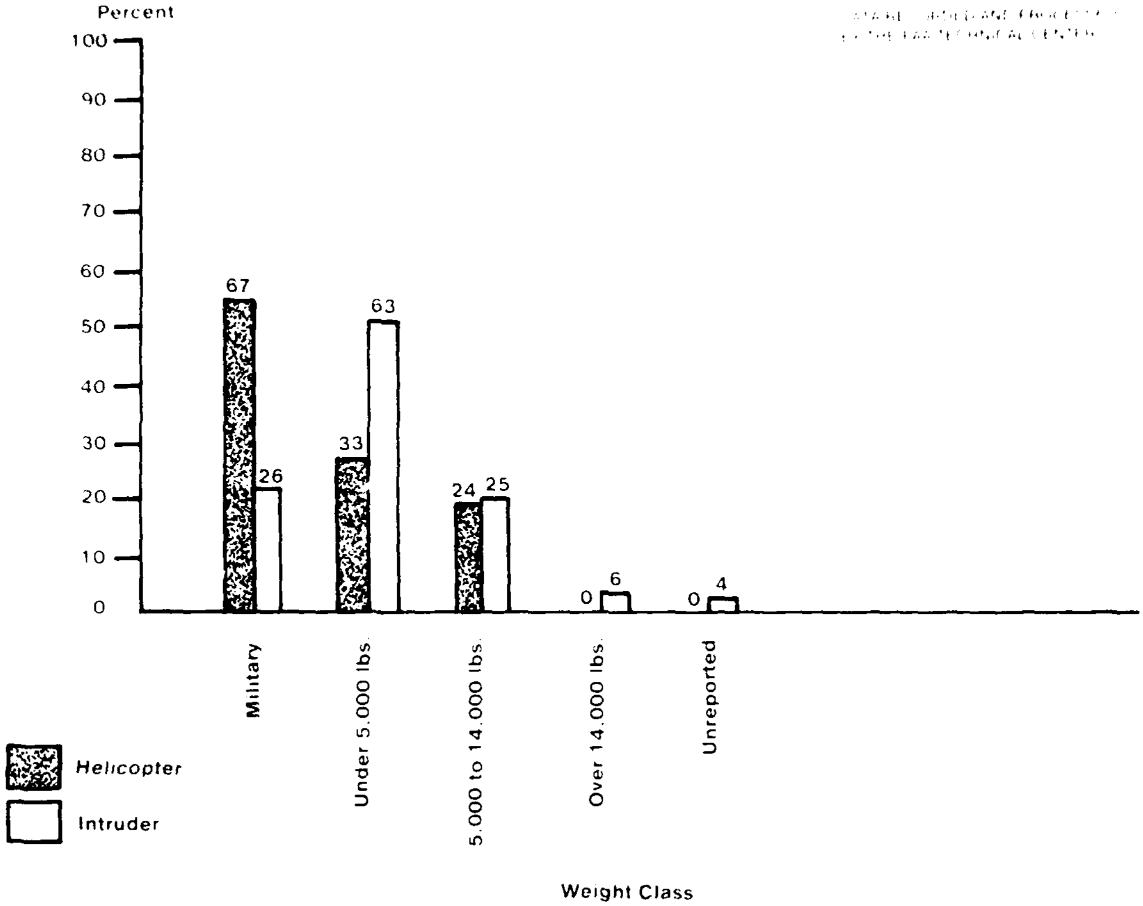

FIGURE 3. GROSS WEIGHT DISTRIBUTION FOR CASES REPORTED BY HELICOPTER CREWS

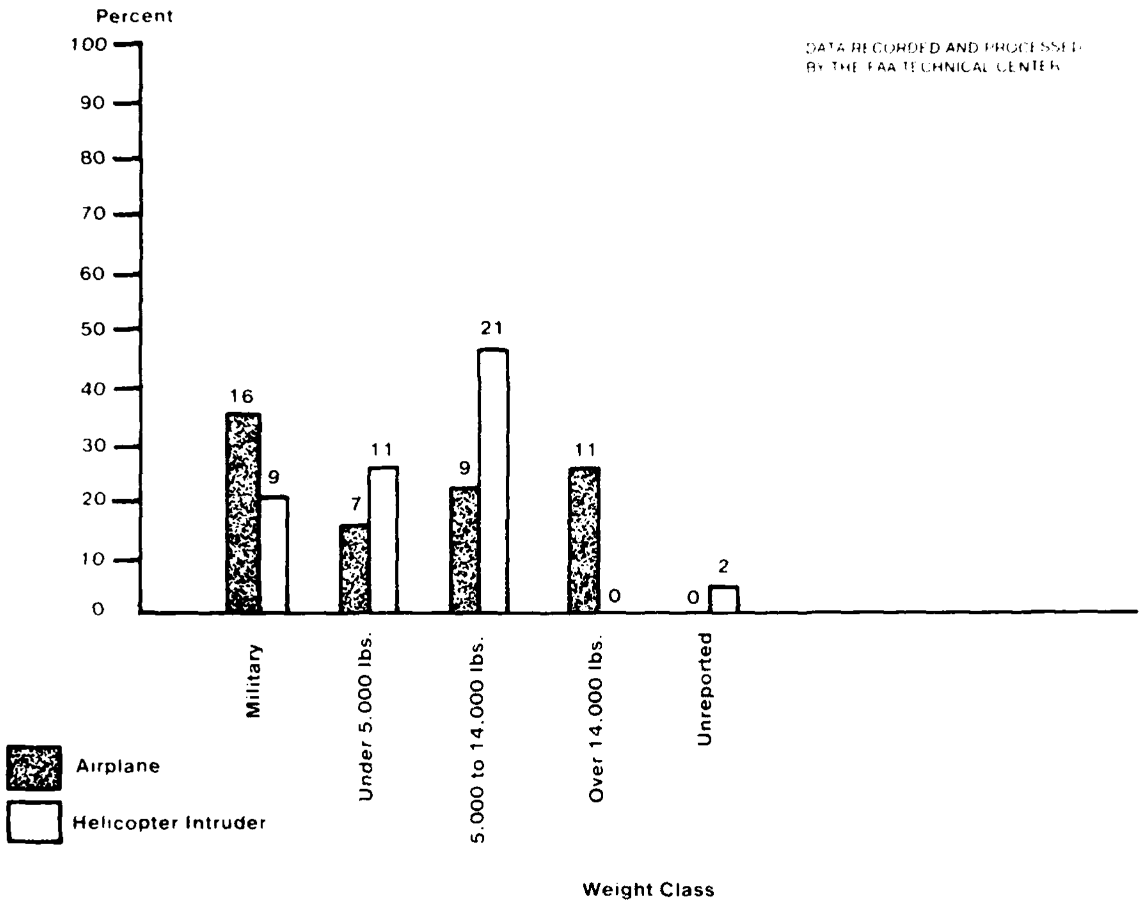

FIGURE 4. GROSS WEIGHT DISTRIBUTION FOR CASES REPORTED BY AIRPLANE CREWS

When the helicopter was considered as the intruder, only seven cases were reported by pilots of airplanes with gross weights less than 5,000 lbs. As a result, probably 85 percent or more airplanes were Mode C equipped. In cases where the helicopter was considered as the intruder, at least 70 percent of the helicopters were probably equipped with Mode C transponders.

PHASE OF FLIGHT. The incidents were reviewed to identify the phases of flight for the aircraft involved in the near mid-air collisions. The information was obtained to identify some rotorcraft TCAS design requirements. Figure 5 presents the reported phases of flight for the aircraft.

Figure 5 indicates 38 percent of the incidents occurred when the helicopter was in the traffic pattern, departing the landing area or arriving at the landing area. The other aircraft was in the traffic pattern, departing the airfield or arriving at the airfield 34 percent of the time. Many of the traffic pattern related incidents occurred at areas without air traffic control facilities. It is interesting to note the distribution of the phases of flight is quite similar for the helicopter and the other aircraft involved in the incident. The only apparent difference was that almost three times as many helicopters were in the maneuvering phase of flight.

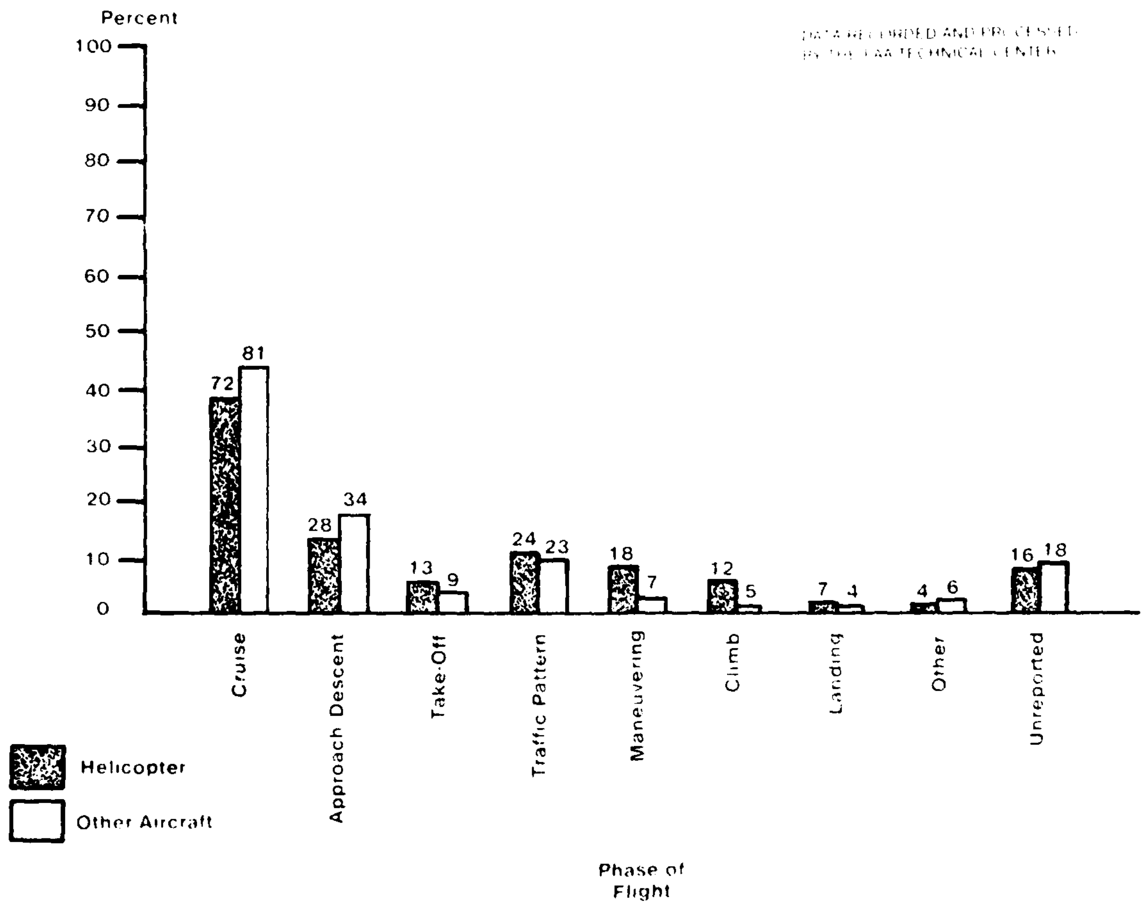

FIGURE 5. DISTRIBUTION OF PHASES OF FLIGHTS

In addition to phase of flight information, most of the narratives contained information about aircraft movement during the encounter. The movement status of the aircraft is presented in table 1.

TABLE 1. AIRCRAFT MOVEMENT STATUS

Movement Status		Frequency		Percent
Both Level		58		31.1
Vertical Movement		101		54.0
One aircraft	66		35.3	
Both aircraft	35		18.7	
Horizontal Movement		21		11.2
One aircraft	9		4.8	
Both aircraft	12		6.4	
Simultaneous Horizontal and Vertical Movement		3		1.6
One aircraft	3		1.6	
Both aircraft	0		0	
Unreported		4		2.1
		187		100.0

In more than one-half of the incidents, vertical movement was reported on the part of at least one aircraft. In 52 encounters (27.8 percent) the intruder aircraft was reported as moving vertically. This information indicates that if the rotorcraft TCAS includes a predictive resolution feature, sophisticated vertical tracking algorithms such as those used in minimum TCAS II are required. Another fact this is apparent is that intruder proximity information should include altitude data when available.

ENCOUNTER CONDITIONS.

RELATIVE BEARING. The encounter conditions were analyzed to identify the distribution of relative bearings that was reported. Figure 6 presents the relative bearing data from the helicopter to the other aircraft. The relative bearing changes throughout the encounter sequence. The first reported relative bearing is the bearing presented in figure 6. Encounters in which the intruding aircraft was not sighted until after closest point of approach are included in the unreported totals. The same is true for cases where the reporting party was not the crew of the helicopter.

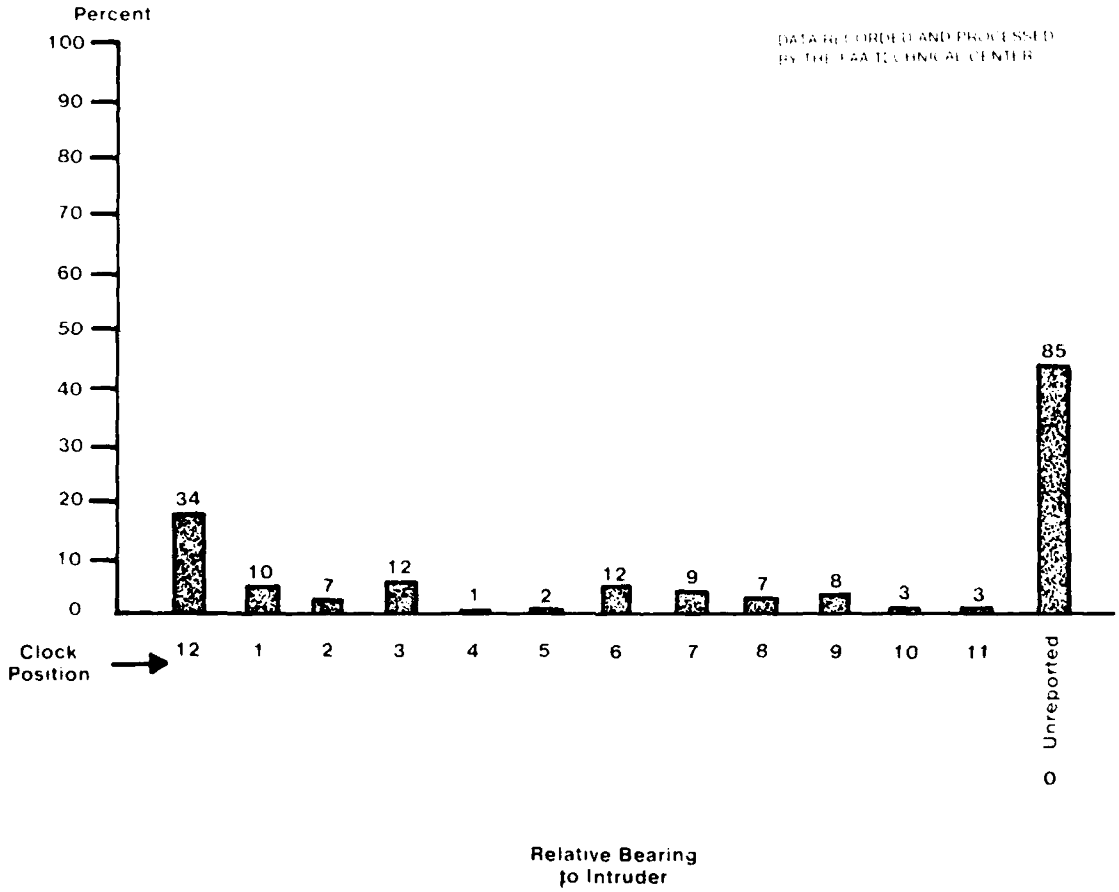

FIGURE 6. DISTRIBUTION OF RELATIVE BEARINGS

In the case where relative bearing was reported, 43.5 percent occurred in the forward quadrant (11, 12, 1 o'clock positions), 35.2 percent broadside (2, 3, 4, 8, 9, 10 o'clock positions), and 21.3 percent in the aft quadrant (5, 6, 7 o'clock positions). There was little difference between intruders appearing in the 8, 9, or 10 o'clock position versus the 2, 3, or 4 o'clock position. A fairly high proportion was reported as occurring in the aft quadrant. This is probably due to increased cockpit visibility in the helicopter.

VELOCITY. The computer listings of incident parameters did not include reporting party or intruder velocity. Velocity information had to be obtained directly from the incident narratives. The distribution of reported velocities is shown in figure 7.

In 3 out of 4 encounters the velocity of the helicopter was not reported. When it was reported, 72.9 percent of the time the velocity ranged between 60 and 100 knots. The maximum reported velocity was 155 knots.

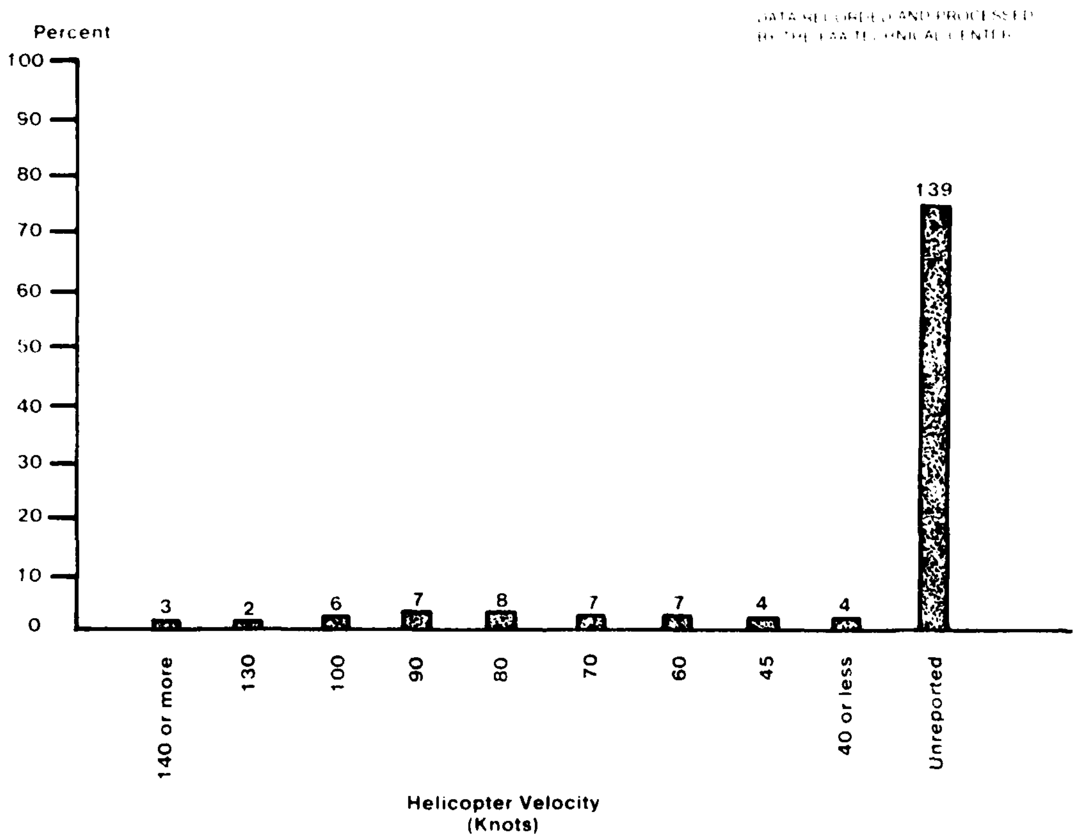

FIGURE 7. DISTRIBUTION OF REPORTED VELOCITIES

ALTITUDE ABOVE GROUND LEVEL. One important consideration is the multipath problems that may exist at the predominent altitudes at which helicopters fly. The near mid-air collision and collision reports were reviewed to identify the distribution of altitude above ground level at which the incidents occurred. On 66 occasions (34 percent) the encounters occurred within 500 feet of ground level. Only 25 percent of the incidents occurred more than 1,500 feet AGL. The maximum reported altitude AGL was 9,000 feet mean sea level (8,700 feet AGL).

WEATHER CONDITIONS.

Parametric data about the weather conditions were obtained from the computer listings and from the narrative descriptions of the incidents. The prevailing weather conditions were cited as a factor by the reporting party in 31 out of the 187 (17 percent) near mid-air collisions.

VISIBILITY. The weather factor most often identified was the in-flight visibility. Figure 8 presents the distribution of reported in-flight visibility when weather was considered as a factor.

In several cases the sun position was identified as restricting visibility even though weather was not considered as a factor.

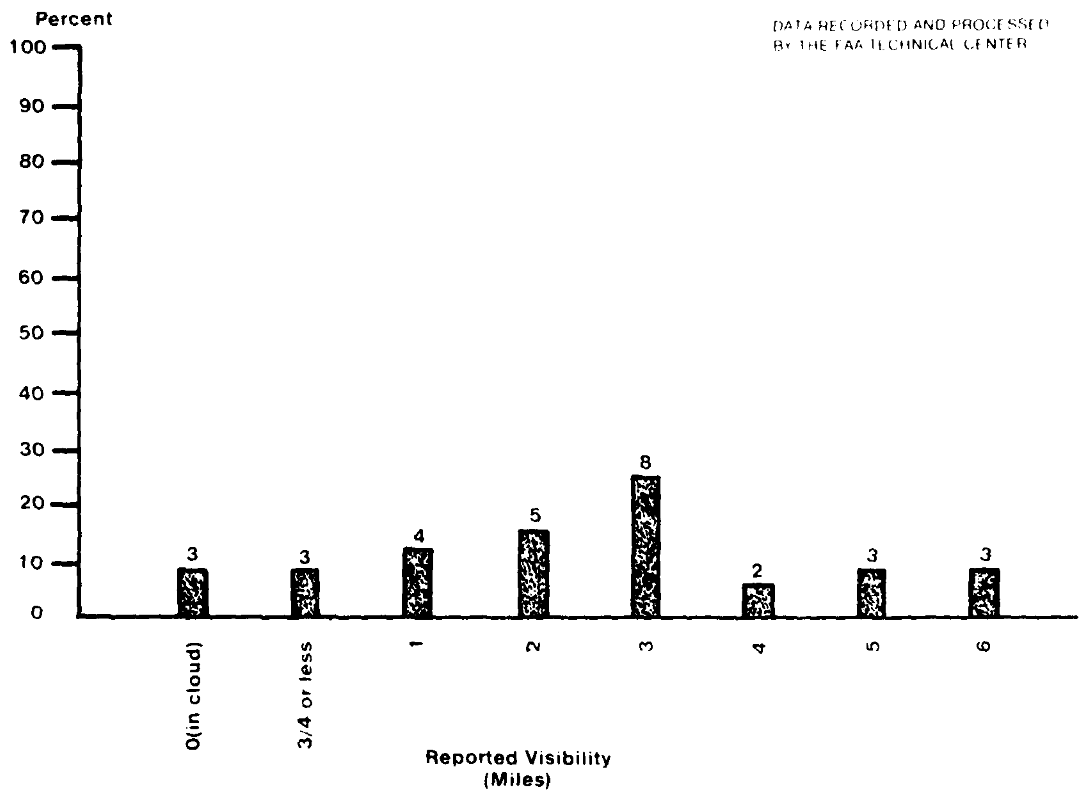

FIGURE 8. REPORTED VISIBILITY WHEN WEATHER WAS CONSIDERED A FACTOR

CEILING. The reported ceiling was also included in the parametric weather conditions which were reported for each encounter. Figure 9 presents the distribution of reported ceilings for incidents in which the reporting party cited the weather conditions as being a factor.

Ten percent of all incidents occurred in weather conditions that did not meet basic VFR weather requirements in controlled airspace (reference 2). In these cases, reported flight visibility was less than 3 miles and/or the aircraft were not operating at least 500 feet below the base of the clouds. However, in only one encounter did the narrative include a statement about violation of any Federal Air Regulations.

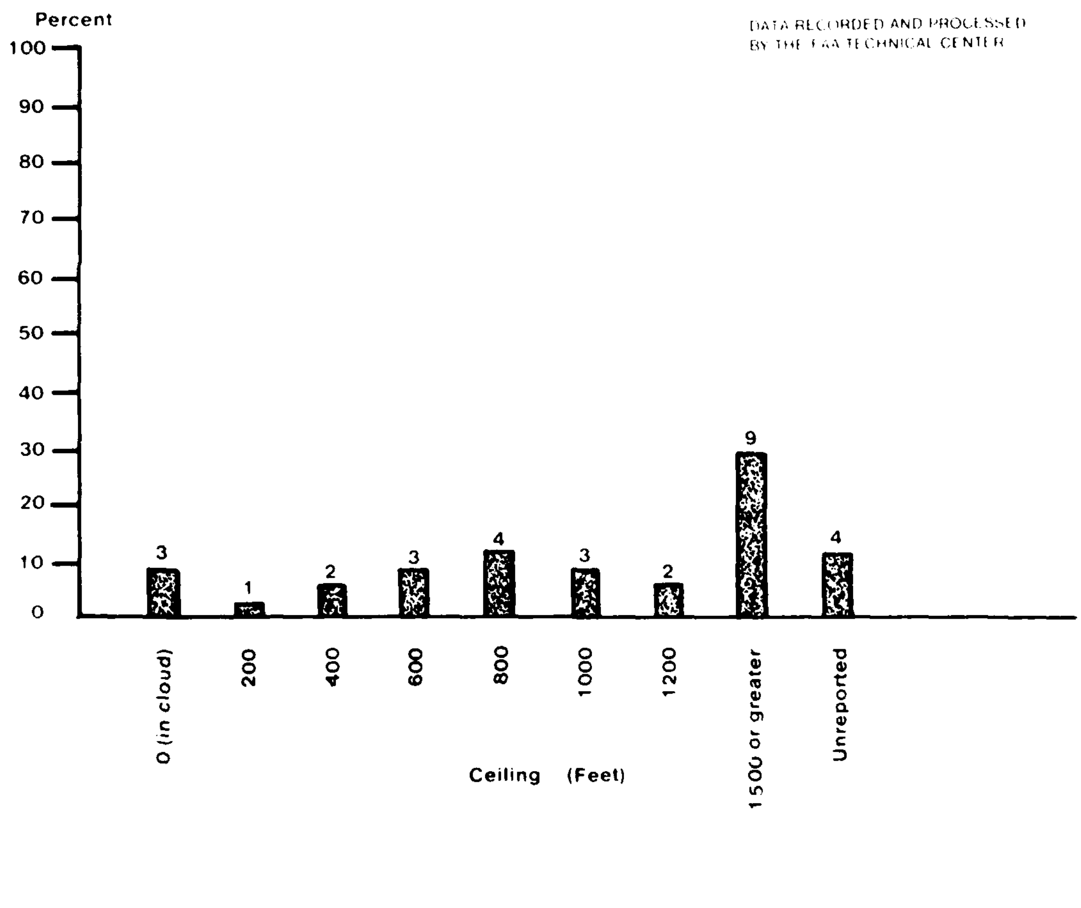

FIGURE 9. REPORTED CEILING WHEN WEATHER WAS CONSIDERED A FACTOR

FLIGHT RULES AND METEOROLOGICAL CONDITIONS. The narratives were reviewed to determine the type of flight rules (VFR = Visual Flight Rules, IFR = Instrument Flight Rules) and the weather conditions (VMC = Visual Meteorological Conditions, IMC = Instrument Meteorological Conditions) the reporting party was operating under. It was difficult to determine the same information for the intruder aircraft. Figure 10 presents the proportion of incidents which occurred for each flight rules/weather condition combination.

The three cases which occurred in IMC conditions but with the aircraft not operating according to IFR require explanations. In one case, an airplane had just broken out of the cloud base on an instrument approach. He canceled IFR and reported the runway in sight. He then had to execute a missed approach to avoid a helicopter which had illegally entered the control zone. The other two cases involved military aircraft operating in warning areas without IFR clearances.

The reporting party was the helicopter crew in only 7 of the 36 cases when the reporting party was operating IFR. When the reporting party was the crew of the helicopter, 94 percent of the time the narratives indicated flight was being conducted in accordance with VFR.

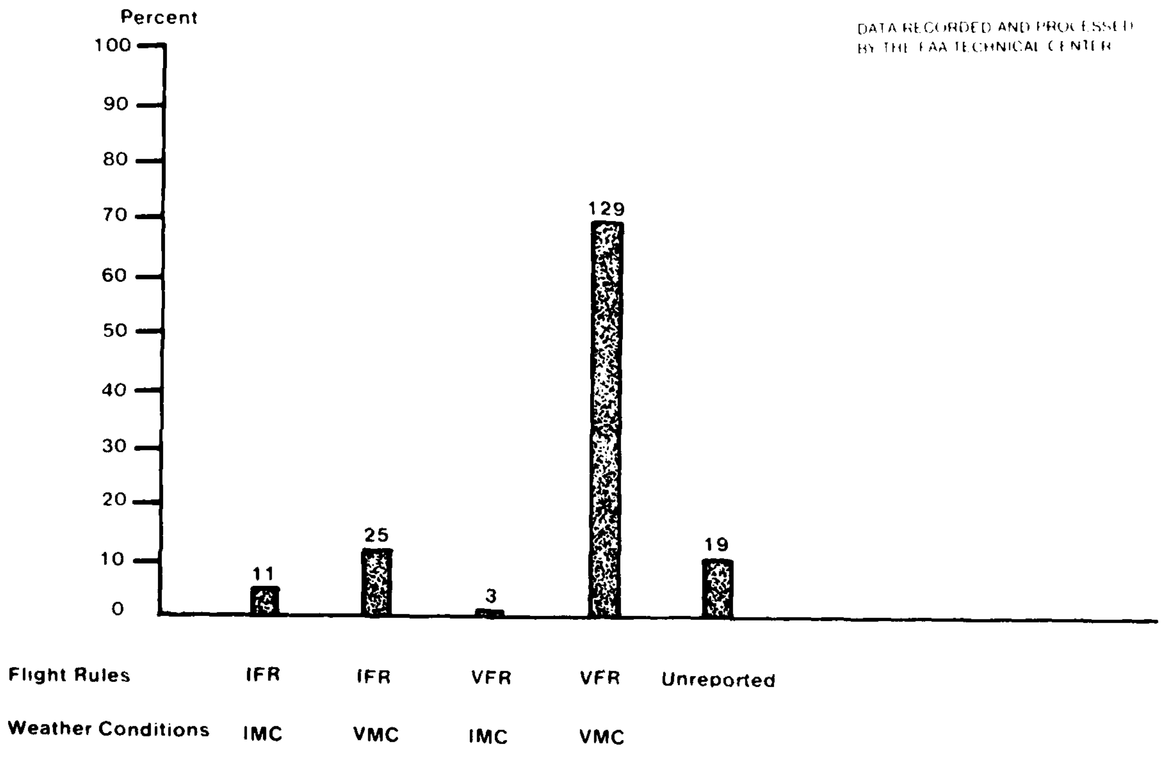

FIGURE 10. OPERATING FLIGHT RULES VERSUS WEATHER CONDITIONS FOR REPORTING PARTY

ATC SERVICES.

An important question which was answered by this survey was what type of ATC service was being provided to the reporting party at the time of the incident. Two general types of service were considered. The first type involved radio communications with an air traffic control tower or with an approach control. The other type of service was radar service being provided by a control tower, approach control, or center. Figure 11 summarizes the services.

In more than half the cases the reporting party was being provided some form of ATC service.

Since in more than one-half the incidents at least one aircraft was being provided with ATC services, the narratives were reviewed to determine what impact the service had on the incident. Figure 12 presents the results of this survey.

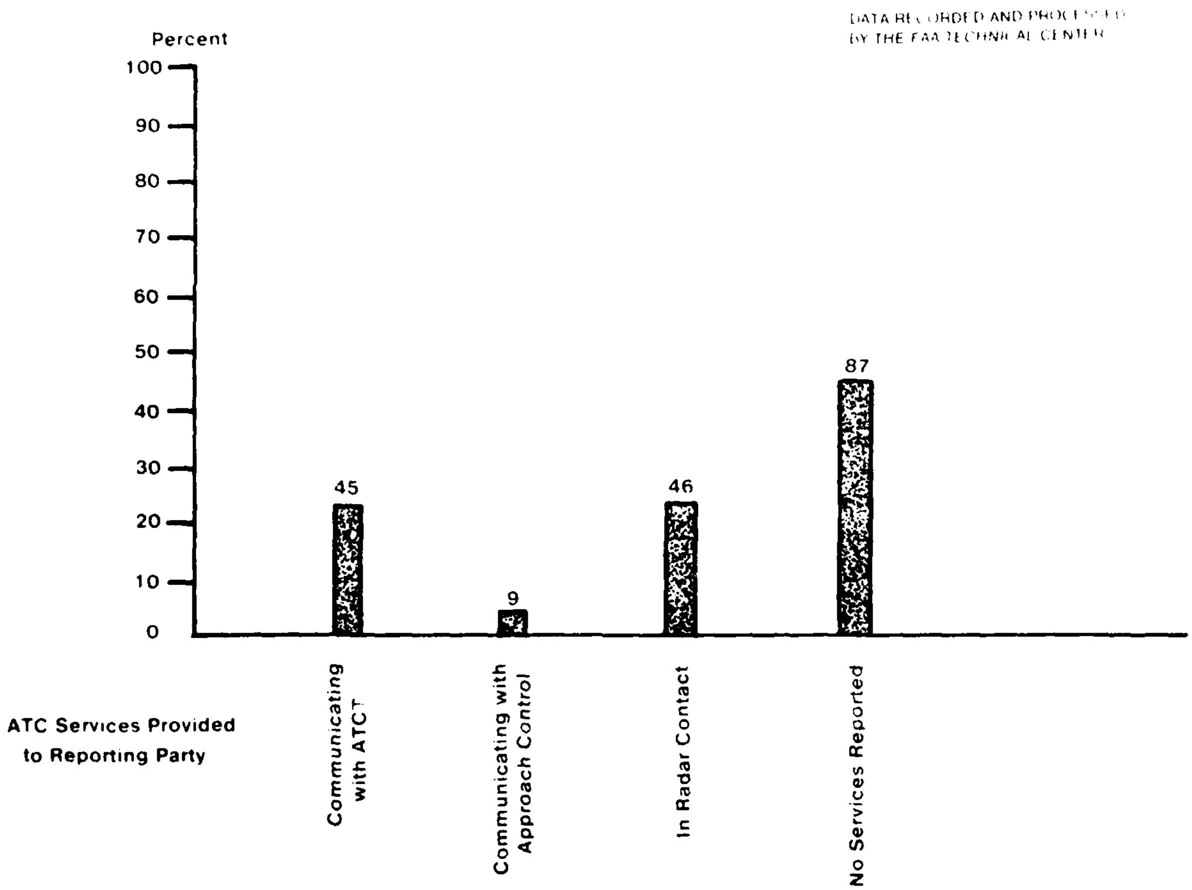

FIGURE 11. ATC SERVICES PROVIDED TO THE REPORTING PARTY

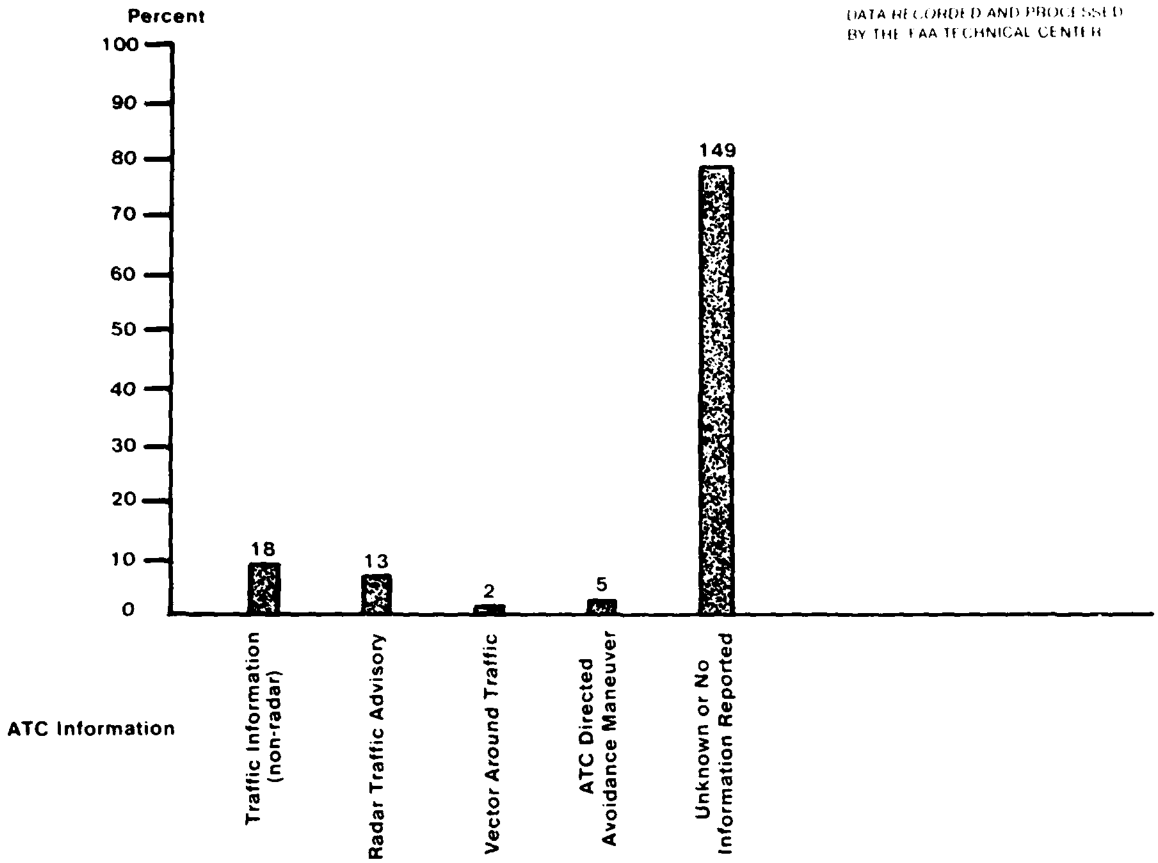

FIGURE 12. ATC INFORMATION RELATED TO THE NEAR MID-AIR INCIDENT

In 20 percent of the incidents, ATC had provided some information to the reporting party. In five cases, the evasive action described by the pilot was initiated because ATC directed avoidance maneuver such as "descent" or "turn right." In two cases the aircraft was given a radar vector to avoid the intruder. This summary reflects information that was provided prior to the closest point of approach.

EVASIVE ACTION.

The final data analyzed determined the need for evasive action and the type of evasive action taken. The cases where the reporting party was the helicopter crew were reviewed. Figure 13 presents the need for evasive action as determined by the reporting party.

In only three cases did the narrative indicate evasive action was not needed. On 18 occasions the narratives stated that evasive action was not taken. On 20 occasions the narrative included the statement that there was no time for evasive action. Specific evasive action by the helicopter was reported 51 times. The evasive action taken is presented in table 2.

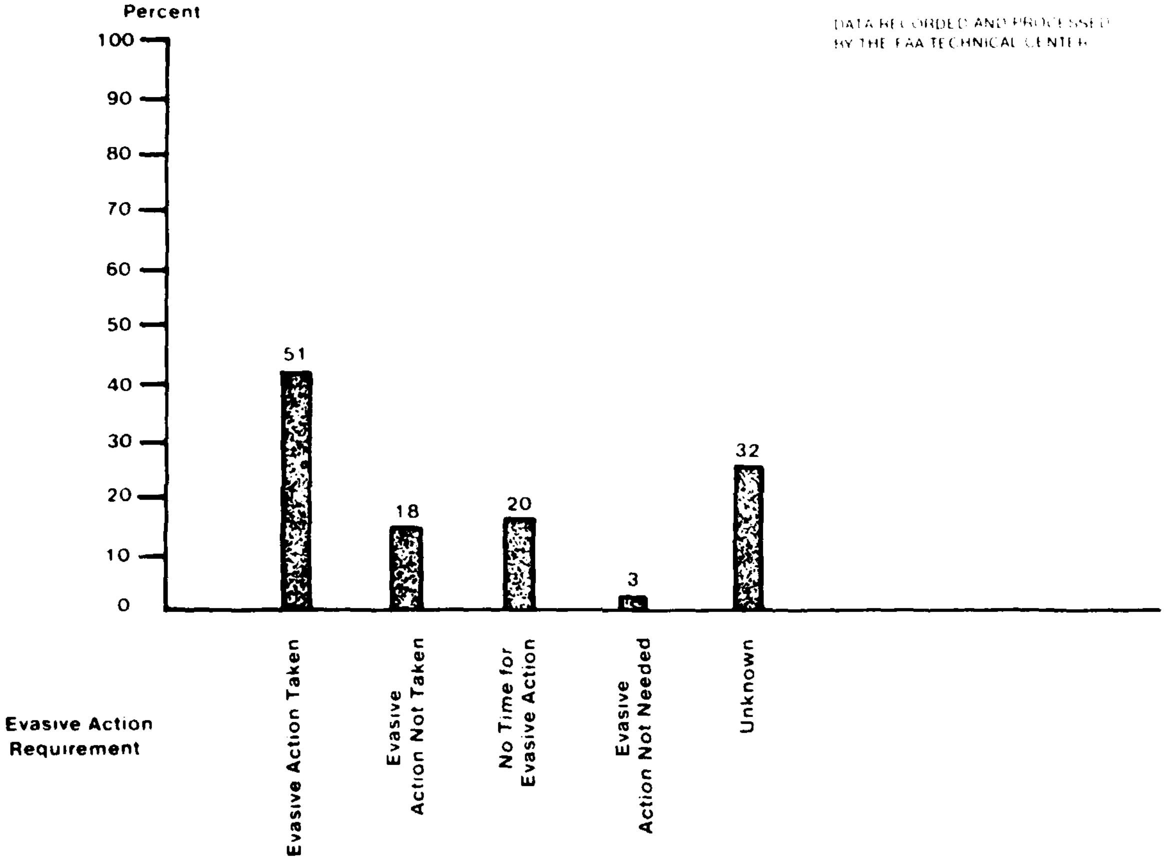

FIGURE 13. EVASIVE ACTION REQUIREMENT

TABLE 2. TYPE OF EVASIVE ACTION TAKEN

Type of Evasive Action			Frequency	Percent
Horizontal Maneuver			13	25.5
Stop Turn	2	3.9		
Left Turn	7	13.8		
Right Turn	4	7.8		
Vertical Maneuver			13	25.5
Climb	4	7.8		
Descend	9	17.7		
Horizontal and Vertical Maneuver			16	31.4
Deceleration			2	3.9
Unreported			7	13.7
			51	100.0

The number of simultaneous horizontal and vertical maneuvers exceeded both horizontal and vertical only maneuvers.

CONCLUSIONS

Based on the review of the near mid-air collision reports, the following conclusions can be made:

1. The geographic location distribution of reported near mid-air encounters and the density distribution of helicopter home bases do not coincide.

2. When a helicopter is involved in a near mid-air incident, the other aircraft is an airplane more than 95 percent of the time.

3. In an encounter between a helicopter and airplane, the incident is reported almost three times more frequently by the helicopter crew than by the airplane crew.

4. More than 11 percent of the incidents involved helicopters performing utility missions involving frequent change in heading, airspeed, and/or altitude. This characteristic may limit the ability of Traffic Alert and Collision Avoidance System (TCAS) to provide a predictive collision avoidance resolution service.

5. More than 11 percent of the incidents involved high-speed, low-altitude military training on a military training route.

6. For the near mid-air collisions, a review of the size of the aircraft involved indicated in more than 60 percent of the incidents both aircraft would have been equipped with Mode C transponders.

7. Results indicate that in 33 percent of the incidents, the helicopter was in the traffic pattern, landing, or taking off.

8. In 52 percent of the incidents, the intruding aircraft was reported as moving vertically. If Rotorcraft TCAS includes a predictive resolution capability, sophisticated vertical tracking algorithms similar to minimum TCAS II tracking algorithms are required.

9. In more than 20 percent of the incidents, the relative bearing to the intruder (from the helicopter) was reported in the aft quadrant (5, 6, 7 o'clock position).

10. Little information was available to determine the distribution of velocities of the helicopters involved in the incidents. When velocity was reported, 72 percent of the time it ranged between 60 and 100 knots. The maximum reported helicopter velocity was 155 knots.

11. The helicopter was less than 500 feet above ground level in 34 percent of the incidents. Only 25 percent of the incidents occurred when the helicopter was more than 1,500 feet above ground level.

12. In 17 percent of the incidents, the reporting party cited the weather as a factor. In these 31 cases, the reported in-flight visibility was 3 miles or less in 23 incidents (12 percent of all encounters).

13. Almost three-quarters of the incidents occurred when the reporting party was operating according to visual flight rules in Visual Meteorological Conditions.

14. In more than one-half of the near mid-air collisions, at least one aircraft was being provided air traffic control services. In 20 percent of the incidents, information relating to the near mid-air collision was provided by air traffic control prior to closest point of approach.

15. In more than one-half of the incidents reported by helicopter crews, evasive action was necessary. The most predominant evasive action was a simultaneous horizontal and vertical maneuver.

REFERENCES

1. Helicopter Operations Survey, R. Adams, Systems Control Technology, June 1982.

2. Federal Air Regulations, 91.119.

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